Moisture Control Strategies for the Building Envelope

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Abstract

Moisture control in buildings is essential to both the inhabitants and the structural performance. Two alternative moisture-control strategies are described. In the first approach, moisture is limited from internal and external sources. The second approach involves constructing for moisture tolerance by preventing entry of liquid water, protecting against air leakage, and appropriately placing vapor retarders. Some consensus-based performance criteria are still needed to provide a consistent basis for moisture analysis and moisture-control strategies. These could benefit building code changes.

Introduction

Moisture control in buildings is necessary to avoid problems with structural performance and human health. Moisture damage is one of the most important factors limiting the useful life of a building. High moisture levels can lead to wood decay metal corrosion, electrical shorts, and discoloration. However, decay and structural damage are by no means the only possible consequences of excessive moisture. Mold and mildew growth in or on the exterior envelope may cause problems with outdoor appearance and indoor air quality. Also, mold is often considered an indication of an environment that is favorable for wood decay. The moisture and humidity conditions conducive to mold and mildew growth are generally less severe than those needed for decay and structural damage. While wood decay is generally believed to initiate at fiber saturation, mold and mildew can grow at surface moisture conditions below fiber saturation. The International Energy Agency (1991) advocates that, to avoid mold growth, the monthly average humidity at interior surfaces not exceed 80%. Relative humidities at a cold wall or window surface can easily reach or exceed this level, even when the relative humidity (RH) in the middle of the room is much lower (e.g., 50% RH). Thus, preventing mold and mildew likely imposes more stringent performance criteria on the envelope and operation of the building than preventing condensation and decay alone.

Moisture problems in the building envelope are usually the result of water or water vapor migrating from the inside or outside of the building to or into the building envelope, and accumulating on or inside the envelope. This migration generally takes place by any of four moisture-transport mechanisms:

- Liquid flow by gravity or air-pressure differences
- Capillary suction of liquid water in porous building materials
- Water vapor by air movement
- Water vapor diffusion

Although, in the past, many moisture control strategies have focused on controlling vapor diffusion by installing vapor (diffusion) retarders, other moisture-transport mechanisms, when present, can move far larger amounts of moisture. In particular, splashback of rainwater onto the bottom of a wall or absorption of rainwater into exterior masonry materials can be important sources of moisture if the water is allowed to migrate into the wall.

Moisture Control Strategies

There are two major approaches to moisture control in the building envelope: 1) limit the moisture load on the building and 2) construct the building so that it exhibits a high tolerance for moisture.

Limiting the Moisture Load. — While the concept of "load" is part of all structural engineering design, where concepts such as live load, wind load, and seismic load are well-established and defined, there is no widely accepted definition of "moisture load." As an intuitive concept, moisture load may be quite clear; for example, normal building envelope assemblies perform well at "normal" indoor humidities, but fail if subjected to unusually high humidity. We will use the term moisture load in this qualitative and intuitive sense for lack of a more rigorous and quantitative definition.

Moisture loads can originate from internal or external sources. In warm humid climates much of the load is external, while in cold winter climates most of the load is internal. Some internal moisture loads result from how the building is constructed, especially the foundation and site preparation, while other loads result from how the building is operated. One type of internal load related to construc-

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tion has often been called "construction moisture," which is water contained in building materials such as wood, concrete, and grout at the time of construction. The amount of moisture can be substantial and allowance must be made for drying. Generally construction moisture should cease to be a problem after the first year following construction. More important through the life of the building is water that enters the building through the foundation because of poor design, a poor site or poor site preparation, or poor oversight during construction (see also Rose and TenWolde on crawl-space design in this issue of Wood Design Focus). In principle, the soil surface that immediately surrounds a building may be thought of as a continuation of the roof. The purpose of that soil surface is to direct water away from the building through proper grading and with the help of downspout extenders, splash blocks, etc. Although it is seldom enforced, most model building codes require a 5% pitch for the first 10 ft (3 m) of soil from the building. Foundation water problems arise when water is allowed to accumulate in the soil that is in direct contact with the basement or crawl-space foundation.

In existing buildings with moisture problems, a change in building operation is often the only practical option to control moisture. This usually involves manipulating indoor temperature and humidity. However, moisture accumulation in the building envelope also can be minimized by controlling the dominant direction of air flow. This may be accomplished by operating the building at a small negative or positive air pressure. In cooling climates, the pressure should be neutral or positive to prevent humid outside air from entering into the envelope. In heating climates, this pressure should be neutral or slightly negative. However, it is important to realize that negative pressure can lead to backdrafting and spilling of combustion products, such as carbon monoxide, from non-sealed combustion equipment. Negative pressure should be avoided in basements or unvented crawl spaces if there is a potential of increased radon release from the soil. Negative pressure also may lead to more soil moisture entering the basement or crawl space.

In heating climates, lowering indoor humidity through source reduction, ventilation, dehumidification, or a combination thereof is an effective moisture-control strategy It is critical that building operators and homeowners monitor the indoor humidity, preferably in more than one location in the building. Some building uses, such as museums, require positive indoor air pressures to ensure filtration of incoming air. In such cases, making the envelope airtight is of paramount concern. In many cold or cool winter climates, house ventilation can be an effective method for removing moisture. Generally the minimum ventilation level of 0.35 air changes per hour (ACH) recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1989) is sufficient to prevent excessive indoor humidity. This ventilation is intended to provide acceptable indoor air quality, yet it also controls humidity. However, in cool coastal climates, which tend to be humid, it may be necessary to remove indoor moisture with dehumidifiers, because the outdoor air contains too much moisture to provide moisture control with ventilation. In general, spot ventilation with bathroom and kitchen fans is also effective in reducing internal moisture loads.

In cold winter climates, the maximum sustainable indoor humidity depends on the thermal and moisture characteristics of the external envelope and the outdoor temperatures. When high indoor humidity occurs in a building with an exterior envelope that has a low "moisture tolerance," disastrous moisture damage may ensue, especially in severe climates. For example, Merrill and TenWolde (1989) reported on severe decay in the sheathing of a group of modular homes in Wisconsin (Figure 1). They found that the frequency of moisture problems was directly related to occupant density (Figure 2). More occupants release more moisture, leading to high indoor humidity, if there is insufficient ventilation. Occupant density was the only parameter that correlated strongly with the frequency of moisture problems. Thus, the authors concluded that the moisture problems were primarily caused by a combination of cold weather and high indoor humidity. However, evidence has since surfaced that particular details in the wall construction may have made the walls of many of these homes more vulnerable to moisture by encouraging moisture to accumulate during the winter, but not allowing rapid drying in the spring. Most likely, a combination of high indoor humidity, low moisture tolerance of the walls, and cold climatic conditions led to major damage to the structure and health problems for the inhabitants.

In cooling climates, indoor temperature and outdoor humidity conditions are the most important parameters in

Figure 1. — Example of damage due to excessive moisture accumulation in a wall during winter.

envelope performance. The cooling equipment needs to be sized appropriately to absorb moisture from indoor sources and moisture that enters with the ventilation air. Moisture-control strategies include raising the indoor temperature and reducing negative indoor air pressures. Less air pressure across a building envelope that is not perfectly airtight reduces the risk of wetting by leakage of humid air into the envelope.

***Constructing for Moisture Tolerance.* —** The building design can render the building envelope more tolerant to high moisture loads (interior or exterior). Constructing for a high tolerance to moisture involves, in order of importance: 1) preventing liquid water from entering the envelope, 2) airtight construction, and 3) placing vapor retarders appropriately. It also includes providing a way for the envelope to dry in case of accidental wetting, and avoiding thermal bridges through the thermal insulation. All of these are most easily accomplished in new construction.

Preventing liquid entry. — Liquid entry can be minimized with capillary breaks (air spaces, nonporous materials), building paper or other weather barriers, proper site grading, gutters and downspouts, and proper flashing and detailing around windows, doors, chimneys, and vent stacks. Adequate roof overhangs also help to keep rainwater off the walls and windows. A common cause of wall deterioration is lack of flashing or caulking; often, water enters between the trim and the siding. For walls, a rain screen is a technique that is often advocated. A rain screen consists of an air-permeable cladding over an airtight backing with an air space in between. Pressure equalization across the rain screen should minimize penetration of wind-driven rain. The rain-screen concept has long been used with wood siding in Scandinavia, but it has not yet been evaluated fully for residential applications in the United States.

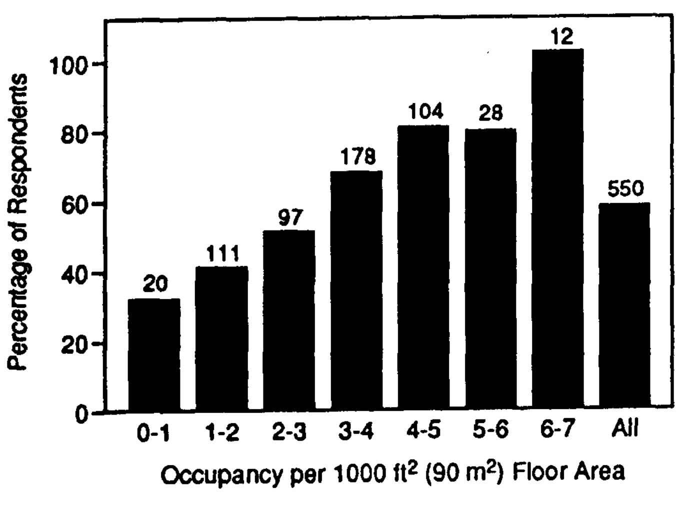

Figure 2. — Incidence of moisture problems as a function of occupancy load, expressed as a percentage of total respondents in each occupancy-load class. Note: The number shown above each bar is the number of respondents reporting problems (Merrill and TenWolde, 1989).

Airtight construction. — Dickens and Hutcheon (1965) were among the first to point out the importance of air movement to water-vapor transport. It can be easily calculated that even a small air flow through an electrical outlet can carry 10 to 500 times as much moisture into a wall as vapor diffusion. Calculated moisture flows are compared in Table 1.

Table 1. — Example[a] of a calculated water vapor flows through a wood frame wall; flow through one stud space with studs 16 in. (400 mm) on center.

Moisture Transport Mechanism .	Water Vapor Flow lb./h (kg/h)
By vapor diffusion:	
No vapor retarder (10 perm)	0.005 (0.0023)
Kraft vapor retarder (1 perm)	0.0005 (0.00023)
Polyethylene vapor retarder (0. 1 perm)	0.00005 (0.000023)
By air leakage through electrical outlet	0.024 (0.011)

Assumptions:
Indoor conditions: 70°F (21°C), 50% RH.
Outdoor conditions: 20°F (-7”C), 50% RH.
Vapor pressure in wall cavity is the same as outdoor.
Effective leakage area (ELA) of outlet [0.016 in. of water (4 Pa) reference pressure], 0.38 in.^{2} (245 mm^2).
Pressure across outlet: 0.004 in. of water (1 Pa).

Vapor retarders. — Thus, air-flow retarders are more critical to moisture control in the building envelope than are vapor retarders. However, Burch and Thomas (1991) and Burch and TenWolde (1993) reconfirmed that vapor retarders are needed on the interior side in airtight walls in cold climates. Burch (1993) also demonstrated the dangers of placing a vapor retarder on the inside of walls in hot humid climates. Conversely, placing a vapor retarder on the exterior of the envelope in cold climates reduces the moisture tolerance of the envelope.

The actual measures depend on whether the local climate is predominantly a heating or cooling climate. Lstiburek and Carmody (1991) recommend a three-step procedure for designing energy-efficient moisture-tolerant roofs, walls, and foundations. First, identify the climate: heating, cooling, or mixed. Second, determine the potential moisture-transport mechanisms in each part of the exterior envelope: liquid flow, capillary suction, air movement, and vapor diffusion. Third, select moisture-control strategies: control moisture entry, control liquid-moisture accumulation (condensation), or remove moisture (by venting, diffusion, or draining).

The current definitions of climate zones are somewhat arbitrary. Lstiburek and Carmody (1991) recommend that heating climates be defined as climates with 4000 or more heating degree days [base 65°F (18°C)]. Cooling climates are defined as warm, humid climates where one or both of the following conditions occur: 1) a 67°F (19°C) or higher

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wet-bulb temperature for 3000 or more hours during the warmest six consecutive months of the year; and/or 2) a 73°F (23°C) or higher wet-bulb temperature for 1500 or more hours during the warmest six consecutive months of the year. Mixed climates are all other climates that are neither heating nor cooling. Heating climates in North America generally include the northern half of the United States, Alaska, and all of Canada. Climates in the southwestern coastal regions of the United States generally can be characterized as cooling climates. However, the local climate should determine whether to design for heating, cooling, or mixed climate conditions.

Not all moisture problems can be avoided at all times. Proper design and construction can help reduce the risk and make a building more tolerant to moisture.

Performance Criteria. — Although there is a growing consensus on effective strategies for reducing the risk of moisture problems, there are as yet no guidelines for determining the appropriate level of protection. Each moisture-control strategy comes with an associated cost, and providing more protection than is needed could be expensive. Should we design buildings to withstand indoor humidities of over 50% RH? Should we prevent condensation anywhere at any time, or is temporary moisture accumulation admissible, as long as it does not cause damage or foster mold growth? To provide a more rational basis for moisture-control decisions and design of the exterior envelope, we need consensus on the appropriate level of moisture tolerance and the performance criteria to be used for the evaluation.

Unfortunately, current building-code requirements for vapor retarders or other moisture-control measures are not based on any definitions of moisture loads (interior or exterior humidity conditions) or moisture-performance criteria. To arrive at a better set of moisture-control strategies and requirements for each climate, we first need to decide which performance criterion should be used. We also need to determine what constitutes an appropriate choice of indoor moisture load for heating climates and indoor temperature for cooling climates. A choice of indoor moisture load could perhaps be based on the use of the building, "typical" moisture release rates for that use, and an appropriate ventilation rate. The performance criteria should relate to the risk of mold growth, structural and other damage to the building envelope, criteria for human health and comfort, and special requirements for specific building uses. These criteria are needed to enable us to answer questions such as "When is construction sufficiently airtight?" and "Where should vapor retarders be required?"

Summary and Recommendations

Moisture control in the exterior envelope should be based on two major strategies: 1) constructing and operating the building such that the moisture load on the envelope is decreased, and 2) building envelope assemblies with a high tolerance for moisture.

A consensus on moisture performance criteria, and on appropriate assumptions for indoor moisture and temperature conditions is needed to provide a consistent basis for moisture analysis of the exterior envelope and for recommendations for moisture-control strategies. Recommendations for "desirable" or "optimum" indoor humidity are not useful in regard to envelope performance or indoor air quality because both depend on microclimatic conditions. These conditions are a function of the thermal integrity air leakage characteristics, and other moisture properties of the building envelope, as well as exterior weather conditions.

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